ENGINEERING PROPERTIES OF COMMON BEAN (*PHASEOLUS VULGARIS* L.) IN PERSPECTIVE OF PHYSICAL AND FRICTIONAL PARAMETERS FOR THRESHING MACHINE DESIGN

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የቦሎቄ (Phaseolus vulgaris L.) የምህንድስና ባህሪያት ለመውቂያ ማሽን ዲዛይን በአካላዊ እና ፍራክሽናል መለኪያዎች አንፃር

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ABSTRACT

When designing appropriate machinery systems, equipment, and infrastructures for interacting with, cultivating, gathering, and agriculture-related processing, it is required to have an understanding of the engineering characteristics of agricultural products. This unpredictability makes it difficult to design or develop machines that can efficiently and effectively manage a wide range of product characteristics. Experimental analysis was used to accomplish the study's objective, which was to investigate the implications of variation on the physical characteristics and frictional parameters of common beans (Phaseolus vulgaris L.) concerning the design of the threshing machine. One hundred bean seeds from each variety were randomly selected and their three primary dimensions were measured with a digital vernier caliper (least count 0.01 mm) and a micro-screw gauge in order to determine the dimensional parameters. The remaining parameters (elongation at the width, thickness, and vertical orientation, geometrical mean diameter, arithmetic mean diameter, square mean diameter, equivalent mean diameter, roundness, sphericity, flakiness ratio, aspect ratio, cross-sectional area, projected area, transverse surface area, and the seed volume) were calculated using mathematical models. Gravimetric characteristics true density and seed volumes were calculated using the toluene displacement method. The data were subjected to analysis of variance (ANOVA), and the Duncan multiple range test was used to separate the means. Significance was accepted at 95% confidence interval ($p< 0.05$).The results data are required for predicting loads in agricultural storage structures, and to establish useful sources for the development of machinery for handling, cleaning, storing, transporting and drying, among other things.

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ከግብርና ጋር ለተያያዙ ግንኙነቶች፣ ለማልማት፣ ለመሰብሰብ እና ለማቀነባበር ተስማሚ የሆኑ የማሽን ስርዓቶችን፣ መሳሪያዎች እና መሠረተ ልማቶችን ሲነድፉ። ይህ ያልተጠበቀ ሁኔታ ብዙ የምርት ባህሪያትን በብቃት ማስተዳደር የሚችሉ ማሽኖችን ለመንደፍ ወይም ለማምረት አስቸጋሪ ያደርገዋል. የሙከራ ትንታኔው የአውድማ ማሽኑን ዲዛይን በሚመለከት የቦሎቄ (Phaseolus vulgaris L.) አካላዊ ባህሪያት እና የግጭት መለኪያዎች ላይ ያለውን ልዩነት ለመመርመር ጥቅም ላይ ውሏል። ከእያንዳንዱ ዝርያ አንድ መቶ የቦሎቄ ዘሮች በዘፈቀደ ተመርጠዋል እና የሶስት ቀዳሚ ልኬቶቻቸው (ርዝመት, ስፋት, ውፍረት ሚሜ) በዲጂታል ቬርኒየር ካሊፐር (ቢያንስ 0.01 ሚሜ) እና በማይክሮ-ስክራው መለኪያ መለኪያዎችን ይለካሉ። ቀሪዎቹ መመዘኛዎች (በስፋቱ፣ ውፍረት እና ቁመታዊ አቅጣጫ ማራዘም፣ ጂኦሜትሪያዊ አማካኝ ዲያሜትር፣ አርቲሜቲክ አማካኝ ዲያሜትር፣ ካሬ አማካኝ ዲያሜትር፣ ተመጣጣኝ አማካኝ ዲያሜትር፣ ክብነት፣ ሉልነት፣ የፍላኪነት ጥምርታ፣ ምጥጥነ ገጽታ፣ መስቀል-ክፍል አካባቢ፣ የታቀደ ቦታ፣ ተገላቢጦሽ የወለል ስፋት; እና የዘር መጠን) የሂሳብ ሞዴሎችን በመጠቀም ይሰላሉ. የግራቪሜትሪክ ባህሪያት እውነተኛ እፍጋት እና የዘር መጠን በቶሉኢን ማፈናቀል ዘዴ (ቲዲኤም) በመጠቀም ይሰላሉ። መረጃው የልዩነት ትንተና (ANOVA) ተደርገዋል፣ እና የዱንካን ባለብዙ ክልል ሙከራ ዘዴዎቹን ለመለየት ጥቅም ላይ ውሏል። ትርጉሙ በ95% የመተማመን ልዩነት ($p< 0.05$) ተቀባይነት አግኝቷል። እነዚህ መረጃዎች የሚፈለጉት በግብርና ማከማቻ መዋቅሮች ውስጥ ያሉ ሸክሞችን ለመተንበይ ብቻ ሳይሆን ለሌሎች ነገሮች አያያዝ፣ ጽዳት፣ ማከማቻ፣ ማጓጓዣ እና ማድረቂያ ማሽነሪዎች ልማት ጠቃሚ ምንጮችን ለማቋቋም ነው።

INTRODUCTION

The common bean is one of the primary worldwide sources of edible legumes (*Phaseolus vulgaris* L.). The leading producers are the US, China, Mexico, Brazil, India, and Mexico (*FAO, 2020*). In 2021, dry beans produced on 28 million hectares worldwide yielded over 20 million tons. Grain-based legumes are essential for nourishment for humans (*Degirmencioglu et al., 2019*), particularly for low-income people in underdeveloped countries (*Fernando, 2021*). Compared to grains, their protein content is almost 2-3 times higher (*Wodajo et al., 2021*), they are composed of a substantial amount of protein and are often referred to as "poor man's meat." For a sizable segment of the global populace, mostly in developing nations, they also provide an affordable and significant source of starch, dietary fiber, and protein (*FAO, 2020*).

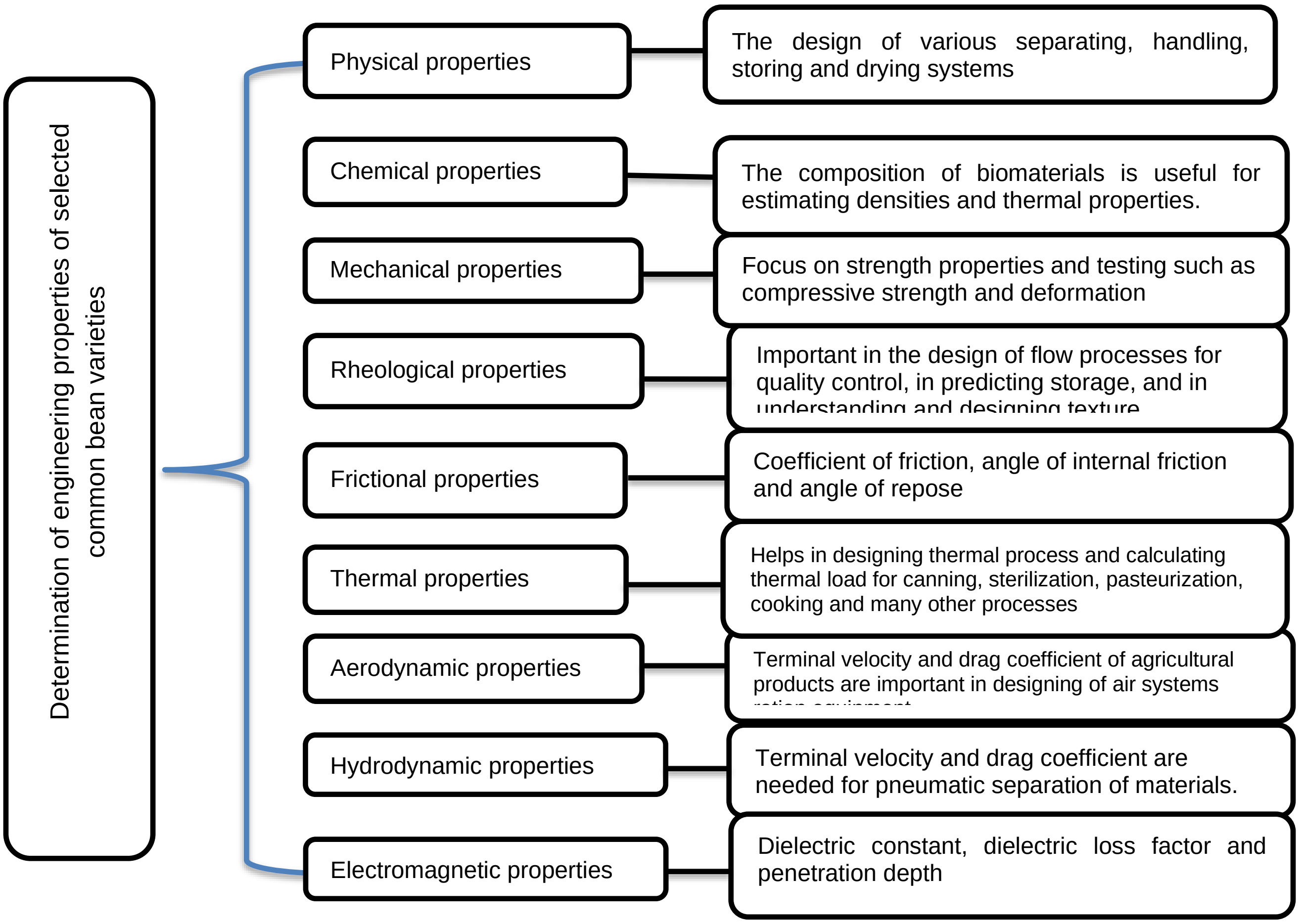
According to *Amsalu et al. (2018),* Ethiopia has been producing and exporting common beans for more than 50 years. The country produces red, white, black, and mottled varieties of common beans (*Abera et al., 2020*). The most widely available commercial kinds are pure red and white beans; as market demand increases, they are also being grown more frequently (*Tekalign et al., 2022*). Due to the increased demand for these commodities in the local and international markets, in recent years, there has been a discernible increase in nationwide production area and volume (*Kefelegn et al., 2020*). This illustrates how inefficient postharvest handling, primarily done by hand, persists in Ethiopia, considering the country's significant worldwide yield of common beans (*Befikadu, 2018*). To build appropriate systems, equipment, and infrastructures for interacting with, cultivating, gathering, and agriculture-related processing, comprehension of the engineering characteristics of agricultural products is essential (Fig.1).

Bayano-Tejero et al. (2023) state that when designing, cleaning, sizing, and grading machines, the three main dimensions of length, breadth, and thickness must be considered *(Samrawit, 2023*). Aspect ratio (*Omobuwajo et al., 1999*), projected area (*Mirzabe et al., 2013*), roundness (*Baryeh, 2002*), sphericity and surface area *(Mohsenin, 1986; Baryeh, 2002*), arithmetic mean diameter and geometric mean diameter (*Baryeh, 2002; Mpotokwane et al., 2008*), and *Mohsenin (1986)* computation of seeds' volume (V) were among the measurements taken. When developing the seed metering mechanism of seed drills (*Önal and Ertuğrul, 2011*), as well as transportation, sorting and sizing systems, bean seed size is a critical parameter (*Nciri et al., 2014*). Larger-seeded bean varieties absorb water more slowly and take longer to cook than smaller-seeded varieties (*Sahin and Sumnu, 2006*). During soaking, seed size affects electrical conductivity tests (*Chhabra and Kaur, 2017*).

Surface area plays a crucial role in heat and mass transfer processes such as drying and various thermal applications. An agricultural product's surface area usually indicates how it will behave in a flowing fluid and how easy it will be to remove unwanted contaminants from the product while cleaning it with a pneumatic tool (*Omobuwajo et al., 1999*). The surface area helps determine the agricultural products quality and quantity, color, respiration data, and aerodynamic calculations (*Singh and Heldman, 2009*).

The physical parameters alter the rate of moisture transfer and heat transfer in the approach, which makes them crucial properties in drying and ventilation processes. The bulk density determines the conveyor capacity and amount of produce storage needed. When separating materials, the actual density is taken into account. Grain hopper and storage equipment sizing is determined by porosity (*Kakade et al., 2019*). The engineering characteristics of agricultural materials are influenced by the moisture content, a physical parameter (*Sahin and Sumnu, 2006; Bhise et al., 2014; Degirmencioglu and Srivastava, 1996; Singh and Heldman, 2009*). Equipment design that is effective, affordable, and efficient depends on having a comprehension of the traits of agricultural materials at varying moisture levels (*Chhabra and Kaur, 2017; Bhise et al., 2014*). When constructing storage and solid flow mechanisms (*Emrani and Berrada, 2023*) and material handling equipment (*Pawar et al., 2023*), another essential consideration to take into account is the coefficient of resistance (*Bako and Aguda, 2023*). An essential factor in predicting pressure from seeds on walls (*Amin et al., 2004*) is the coefficient of friction (*Bhise et al., 2014*) between the seed and the wall.

Hence, agricultural products have inherent variability in their engineering parameters, including moisture contents, size, shape, surface area, sphericity, density (both bulk & true), porosity, volume of seed, coefficient (both static & dynamic), and angle of repose (*Jahanbakhshi, 2018; Ertuğrul et al., 2022*). This variability poses challenges in designing, modification, improvement, or development of machines efficiently and effectively. A lack of thorough data, inconsistent testing procedures, and a poor comprehension of the relationship between the agricultural product and the machine are a few additional challenges (*Elijah et al., 2018*). The aim of this article is to find out how the physical and frictional characteristics of common beans (*Phaseolus vulgaris* L.) influence the design of a thresher for a particular bean variety.



Model developed by Author, 2024

Fig. 1 – Conceptual study model of engineering properties common bean seeds

MATERIALS AND METHODS

Materials

Awash Melkassa Research Center, Oromia regional State, Ethiopia, provided three improved varieties of common beans that grow in several regions of the country: KAT-B1, KAT-B9, and SCR-15 (Fig. 2). One hundred bean seeds from each variety were randomly selected and their three primary dimensions were measured with a digital vernier caliper (least count 0.01 mm) and a micro-screw gauge in order to determine the dimensional parameters. For further investigation, the sample seeds were cleaned of foreign elements such as dust, stones, dirt, immature seeds, damaged seeds, and other contaminants. Then, in an airtight plastic vessel, the healthy seeds that had been chosen were kept at 5°C. The seeds were allowed to attain the room temperature before the test began.

KAT B1 (Katumani Bean 1) **KAT B9 (Katumani Bean 9)** **SCR 15**

Fig. 2 – Awash Melkassa Research Center's national common bean research programs improved varieties

Laboratory

All of the tests were carried out at the Agricultural Engineering Laboratories at Melkassa Agricultural Research Center (MARC), Haramaya University, and Adama Science & Technology University's; Science, Technology, Engineering, & Mathematics (ASTU STEM) Center's.

Methods - Experimental procedure

The dimensions of three hundred (100 for each variety) randomly chosen bean seeds were determined. Using an electronic vernier caliper with a precision of 0.01 mm, the three fundamental axial dimensions of Phaseolus vulgaris were measured. *Phaseolus vulgaris* mean diameters were computed as geometric mean (D_g), arithmetic mean (D_a), square mean (D_s), and equivalent mean (D_e) were determined using equations (1–4) (*Fraser et al., 1978; Mohsenin, 1986; Baryeh, 2002; Haciseferogullari et al., 2003; Altuntas and Yildiz, 2007*; *Sundaram et al., 2014*).

Geometric Mean Diameter, mm $$\boldsymbol{D_g} = \sqrt[3]{\boldsymbol{L} \times \boldsymbol{W} \times \boldsymbol{T}} \quad (1)$$

Arithmetic Mean Diameter, mm $$D_a = \frac{L + W + T}{3} \quad (2)$$

Square Mean Diameter, mm $$D_{sq} = \sqrt{LW + WT + TL} \quad (3)$$

Equivalent Mean Diameter, mm $$D_{eq} = \frac{D_g + D_a + D_s}{3} \quad (4)$$

Using equations (5–11) adopted by *Mohsenin, (1986); Baryeh, (2002); Gupta et al., (2007); Sirisomboon et al., (2007); Mirzabe et al., (2013),* the surface area, projected area, specific surface area, transverse surface area, cross-section area, and volume of the seeds were calculated.

Surface Area seed, mm^2
$$A_s = \pi {D_g}^2 \quad (5)$$
$$A_s = (36\pi)^{\frac{1}{3}} V^{\frac{2}{3}} \quad (6)$$

Projected Area, mm^2 $$A_p = \left(\frac{\pi}{4}\right) L * W \quad (7)$$

Specific Surface Area, mm^2 $$S_s = {A_s \rho_b}/{m} \quad (8)$$

Transverse Surface area, mm^2 $$A_t = \left(\frac{\pi}{4}\right) T * W \quad (9)$$

Cross-Section Area, mm^2 $$CSA = \frac{\pi}{4}\left[\frac{(L + W + T)^2}{3}\right] \quad (10)$$

Volume of the seed, mm^3 $$V = \frac{\pi B^2 L^2}{6(2L - B)}; \ B = (WT)\ 0{:}5 \quad (11)$$

where; B = (WT) $^{0:5}$; the seeds' width, W, and thickness, T, are measured in mm, L, length in mm.

Using the algorithms described by several references *(Mohsenin, 1986; Omobuwajo et al., 1999; Baryeh, 2002; Chhabra and Kaur, 2017; Saparita et al., 2019*), the flakiness ratio, aspect ratio, shape index, shape factor, sphericity, and roundness of the common beans were computed using the following equations (12–17).

Flakiness Ratio $$R_f = {T}/{W} \times 100\% \quad (12)$$

Aspect Ratio $$R_a = {W}/{L} \times 100\% \quad (13)$$

Shape Index $$SI = L/\sqrt{(W * T)} \quad (14)$$

Shape Factor $$SF = {}^{4\pi P_A}/_{P^2} \quad (15)$$

Sphericity $$\varphi = \left(\frac{WT}{L^2}\right)^{1/3} \quad (16)$$

Roundness $$R = \left\{\frac{{}^{W}/_{L} + {}^{T}/_{L} + {}^{T}/_{W}}{3}\right\} \quad (17)$$

Using the following equations (18, 19, and 20) adopted by *(Mohsenin, 1986*), the elongation at the width orientation (*Gupta et al., 2007*), elongation at the thickness orientation (*Mirzabe et al., 2013*), and elongation at the vertical orientation (*Chhabra and Kaur, 2017*) of the *Phaseolus vulgaris* were determined.

Elongation at the width orientation $$E_w = {}^{L}/_{W} \quad (18)$$

Elongation at the thickness orientation $$E_t = {}^{L}/_{T} \quad (19)$$

Elongation at the vertical orientation $$E_v = {}^{W}/_{T} \quad (20)$$

Determination of gravimetric parameters

The true density and seed volumes were determined using the liquid displacement technique. Water was not utilized since the seed absorbs water more readily than toluene (C_7H_8). To measure the amount of toluene displaced from the weighted seed, the amount of the product that was displaced was measured using a graduated scale on the cylinder. Once the weight of the seeds was divided by the volume of displaced toluene, their true density was found. Bulk density, true density, and porosity were calculated using equations 21–25, (*Mohsenin, 1986; Desphande et al., 1993; Omobuwajo et al., 1999; Singh and Heldman, 2009; Saparita et al., 2019*).

Thousand Seed Mass (TSM) $$TSM = \frac{Weight\ of\ sample, g}{Number\ of\ grains\ in\ sample} \times 10 \quad (21)$$

Bulk Density, *kgm*$^{-3}$ $$\rho_b = \frac{Weight\ of\ \ sample\ (g)}{Volume\ of\ occupied\ (cm^3)} \quad (22)$$

True Density, *kgm*$^{-3}$ $$\rho_t = \frac{Weight\ of\ the\ sample\ (g)}{Volume\ of\ toluene\ displaced\ (cm^3)} \quad (23)$$

Density Ratio, *(%)* $$R_\rho = \left(\frac{\rho_b}{\rho_t}\right) \times 100(\%) \quad (24)$$

Porosity, *(%)* $$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100(\%) \quad (25)$$

Determination of angle of repose

Two cylindrical diameter containers, one hollow and placed on top of a closed side, were used in the setup for the experiment for measurements of the repose angle (Fig. 3). Using equation (26) as provided by *Baryeh (2002), Mohsenin (1986), Saparita et al. (2019),* likewise the repose angle (υ) and the apex height were taken into consideration were computed using the trigonometry rule.

Coefficient of static friction determination

Ten surfaces' coefficient of static friction was computed using the inclined plane approach. The angle of inclination (ϕ) was found using the protractor attached to the apparatus after the table had been gently raised to the horizontal at which the seeds began to slide. Equation (27) was utilized to compute the static friction coefficient (μ), following the method outlined by *Mohsenin (1986)* and *Saparita et al. (2019),* albeit with some adjustments.

Angle of repose/inclination: $$\phi = \tan^{-1}\left[{h}/{b}\right] \quad (26)$$

Coefficient of static friction $$\mu = tan\phi \quad (27)$$

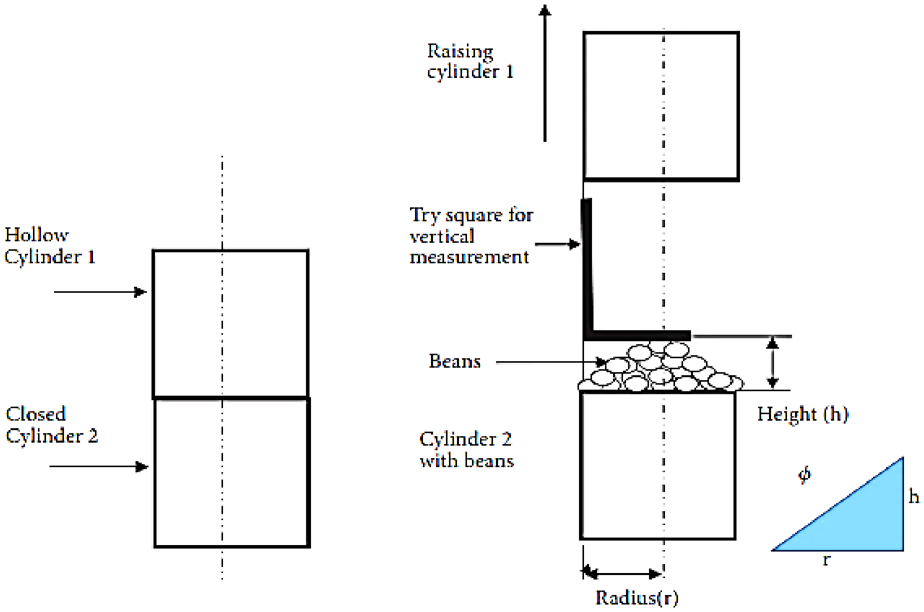


Fig. 3 – Experimental setup for repose angle measurements

Statistical Analysis

The standard deviation (SD) and mean of the results were displayed. Using IBM SPSS Statistics 27.0.1_IF026 and the Statistical Package for Social Science, version 22, way analysis of variance (ANOVA) was performed on the data.

RESULTS

Table (1a) shows a summary of the measured and determined dimensional parameters. For the three *Phaseolus vulgaris* (common bean) varieties KAT-B1, KAT-B9, and SCR-15, the physical parameter ANOVA values are shown in table 1a. The length, width, thickness, elongation ratios (at width, thickness, and vertical), arithmetic mean diameter, geometric mean diameter, square mean diameter, and equivalent mean diameter are among the physical parameters that are evaluated. The table displays the mean ± standard deviation, coefficient of variation, variance, maximum, minimum, and variance for each parameter. The findings verified that the seeds' longitudinal dimensions ranged from 8.25 to 15.67 mm, with an average mean value (amv) of 11.282 ± 0.995 mm; their width varied from 4.44 to 10.46 mm, with an amv of 7.24 ± 0.673 mm; their seed thickness ranged from 3.09 to 8.11mm, with an amv of 5.67 ± 0.794 mm; their elongation of width (Ew) varied from 1.024 to 2.748 mm, with an amv of 1.566 ± 0.136 mm; their elongation of thickness (Et) varied from 1.389 to 3.408 mm, with an amv of 2.037 ± 0.282 mm; and their elongation of vertical (Ev) varied from 0.671 to 2.104 mm, with an amv of 1.301 ± 0.152 mm. The significance of axial dimensions in machine design was emphasized by *Mohsenin (198*6). However, symmetric projections towards process equipment adaption can be made by comparing the results with previous research on other seeds.

Table 1a

ANOVA values physical properties of selected *Phaseolus vulgaris* varieties

Parameters	Variety	Mean	Max	Min	Variance	STDEV	CV%	Mean±STDEV
Length, mm	KAT-B1	11.521^{ns}	15.670	9.050	1.195	1.093	9.487^{ns}	$11.521±1.093^{ns}$
	KAT-B9	10.769^{ns}	12.960	8.250	0.862	0.928	8.620^{ns}	$10.769±0.928^{ns}$
	SCR-15	11.556^{ns}	14.290	8.970	0.931	0.965	8.350^{ns}	$11.556±0.965^{ns}$

Parameters	Variety	Mean	Max	Min	Variance	STDEV	CV%	Mean±STDEV
Width W (mm)	KAT-B1	7.608*	10.460	6.220	0.382	0.618	8.124*	7.608±0.618*
	KAT-B9	6.795*	8.310	4.440	0.493	0.702	10.334*	6.795±0.702*
	SCR-15	7.317*	8.910	5.940	0.488	0.699	9.548*	7.317±0.699*
Thickness T (mm)	KAT-B1	6.213*	8.110	4.660	0.291	0.540	8.685*	6.213±0.540*
	KAT-B9	5.637*	7.470	3.090	1.370	1.171	20.765*	5.637±1.171*
	SCR-15	5.159*	6.780	3.440	0.451	0.672	13.019*	5.159±0.672*
Elongation at width E_w	KAT-B1	1.519*	1.999	1.024	0.020	0.140	9.196*	1.519±0.140*
	KAT-B9	1.593*	2.748	1.298	0.022	0.149	9.342*	1.593±0.149*
	SCR-15	1.586*	1.832	1.238	0.014	0.120	7.560*	1.586±0.120*
Elongation at thickness E_t	KAT-B1	1.866*	2.663	1.493	0.050	0.225	12.034*	1.866±0.225*
	KAT-B9	1.976*	3.408	1.390	0.126	0.355	17.967*	1.976±0.355*
	SCR-15	2.267*	2.922	1.543	0.071	0.267	11.784*	2.267±0.267*
Elongation at vertical E_v	KAT-B1	1.231*	1.622	0.970	0.014	0.119	9.646*	1.231±0.119*
	KAT-B9	1.241*	2.104	0.671	0.040	0.199	16.020*	1.241±0.199*
	SCR-15	1.431*	1.802	1.088	0.020	0.140	9.763*	1.431±0.140*
Arithmetic mean diameter (D_a), mm	KAT-B1	8.447	10.090	6.913	0.317	0.563	6.664	8.447±0.563
	KAT-B9	7.734*	9.563	5.853	0.712	0.844	10.911*	7.734±0.884*
	SCR-15	8.011*	9.517	6.427	0.434	0.659	8.222*	8.011±0.659*
Geometric mean diameter (D_g), mm	KAT-B1	8.152^{ns}	9.429	6.732	0.272	0.521	6.397^{ns}	8.152±0.521^{ns}
	KAT-B9	7.421*	9.280	5.592	0.827	0.909	12.255*	7.421±0.909*
	SCR-15	7.571*	8.924	5.985	0.439	0.662	8.747*	7.571±0.662*
Square mean diameter (D_{sq}), mm	KAT-B1	14.357	16.786	11.811	0.865	0.930	6.478^{ns}	14.357±0.930^{ns}
	KAT-B9	13.105	16.295	9.891	2.294	1.514	11.557^{ns}	13.105±1.514^{ns}
	SCR-15	13.477	15.857	10.760	1.300	1.140	8.460^{ns}	13.477±1.140^{ns}
Equivalent mean diameter (D_{eq}), mm	KAT-B1	10.319*	12.092	8.485	0.448	0.670	6.490*	10.319±0.670*
	KAT-B9	9.420*	11.713	7.112	1.185	1.088	11.554*	9.420±1.088*
	SCR-15	9.686^{ns}	11.394	7.729	0.670	0.819	8.453^{ns}	9.686±0.819^{ns}

**Significant at P≤ 0.05, ns non-significant, CV = Coefficient of Variation, VARA = variance, STDEV = Standard deviation*

The seeds' arithmetic mean diameter ranged from 5.853 to 10.793 mm, with an amv of 8.064 ± 0.688 mm; their geometrical mean diameter varied from 5.592 to 9.279 mm, with an amv of 7.715 ± 0.698 mm; their square mean diameter varied from 9.891 to 18.047 mm, with an amv of 13.646 ± 1.195 mm; their equivalent mean diameter varied from 7.112 to 12.994 mm, with an amv of 9.808 ± 0.859 mm; their roundness ranged from 0.537 to 0.760 mm, with an amv of 0.644 ± 0.056; their sphericity varied from 0.595 to 0.803 with an amv of 0.685 ± 0.044; their flakiness ratio varied from 0.594 to 0.966 with an amv of 0.784 ± 0.092; their aspect ratio varied from 0.539 to 0.847, with an amv of 0.643 ± 0.053; cross-sectional area varied from 76.403 to 156.528 mm^2 with the mean value of 154.477 ± 26.002 mm^2, the projected area ranged from 32.827 to 67.175 mm^2 with the amv of 64.508 ± 10.377 mm^2, the transverse surface area varied from 14.828 to 34.343 mm^2 with the mean value of 32.546 ± 6.683 mm^2, and the seed volume varied from 83.752 to 245.872 mm^3 with the mean value of 241.744 ± 0.207 mm^3, respectively.

The findings indicate that the three *Phaseolus vulgaris* varieties differ significantly ($p < 0.05$) in terms of width, thickness, elongation ratios, arithmetic mean diameter, geometric mean diameter, and equivalent mean diameter. There were not any significant variations in length, square mean diameter, or certain elongation ratios within the varieties. When it came to the physical parameters, KAT-B1 was typically the variety with the highest mean values, followed by SCR-15 and KAT-B9. With the exception of thickness in KAT-B9, which had a higher CV of 20.765%, the coefficient of variation (CV %) data indicate moderate variability within the bean samples for the majority of characteristics.

The values should be given for arithmetic, geometric, and sphericity were comparable to those of *Ozturk et al., (2009), Amin et al., (2004)*, and *Kumar and Sharma, (2021)*. Nonetheless, they were lower than those reported by Cetin (2007) and Altuntas and Yildiz (2007), but greater than common beans (*Ozturk et al., 2009*) and lower than red kidney beans with speckles (*Isık and Unal, 2007*).

Table (1b) shows a summary of the measured and determined dimensional parameters. Surface area (As), projected area (AP), area of transverse surface (At), cross-section area (CSA), volume (V), aspect ratio (Ra), flakiness ratio (R_f), sphericity (φ), and roundness are among the physical characteristics that are examined. The variations in the mean values between the three varieties are below the threshold for statistical significance (p>0.05) for the remaining parameters, which include surface area, projected area, area of transverse surface, cross-section area, and volume.

Overall, the shape-related parameters (aspect ratio, flakiness ratio, sphericity, and roundness) and the size-related parameters (surface area, projected area, transverse surface area, cross-section area, and volume) of the three Phaseolus vulgaris varieties (KAT-B1, KAT-B9, and SCR-15) showed statistically significant differences.

Table 1b

ANOVA values physical properties of selected *Phaseolus vulgaris* varieties

Parameters	Variety	Mean	Max	Min	Variance	STDEV	CV%	Mean±STDEV
Surface area(A_s), mm^2	KAT-B1	208.680^{ns}	279.159	142.294	0.232	0.854	0.409^{ns}	208.68±0.409^{ns}
	KAT-B9	172.927^{ns}	270.398	98.199	2.148	2.597	1.502^{ns}	172.927±1.502^{ns}
	SCR-15	180.007^{ns}	250.038	112.462	0.604	1.377	0.765^{ns}	180.007±1.377^{ns}
Projected Area (A_p), mm^2	KAT-B1	69.018^{ns}	96.439	46.320	101.650	10.082	14.608^{ns}	69.018±10.082^{ns}
	KAT-B9	57.794^{ns}	84.543	33.404	101.758	10.088	17.454^{ns}	57.794±10.088^{ns}
	SCR-15	66.712^{ns}	99.949	45.082	120.149	10.961	16.431^{ns}	66.712±10.961^{ns}
Area of transverse surface(A_t), mm^2	KAT-B1	37.198^{ns}	52.962	25.452	25.659	5.065	13.618^{ns}	37.198±5.065^{ns}
	KAT-B9	30.570^{ns}	48.403	15.677	79.283	8.904	29.127^{ns}	30.570±8.904^{ns}
	SCR-15	29.870^{ns}	44.341	16.742	36.943	6.078	20.349^{ns}	29.870±6.078^{ns}
Cross-Section Area(CSA), mm^2	KAT-B1	168.786^{ns}	239.758	112.555	505.740	22.489	13.324^{ns}	168.786±22.489^{ns}
	KAT-B9	142.513^{ns}	215.382	80.686	939.906	30.658	21.512^{ns}	142.513±30.658^{ns}
	SCR-15	152.131^{ns}	213.285	97.266	618.027	24.860	16.341^{ns}	152.131±24.860^{ns}
Volume (V), mm^3	KAT-B1	283.792^{ns}	439.093	159.794	0.011	0.074	0.026^{ns}	283.792±0.074^{ns}
	KAT-B9	214.079^{ns}	418.585	91.609	0.296	0.394	0.184^{ns}	214.079±0.394^{ns}
	SCR-15	227.360^{ns}	372.209	112.277	0.044	0.152	0.067^{ns}	227.360±0.152^{ns}
Aspect Ratio, R_a	KAT-B1	0.664*	0.977	0.500	0.004	0.062	9.288*	0.664±0.062*
	KAT-B9	0.632*	0.770	0.364	0.002	0.047	7.377*	0.632±0.047*
	SCR-15	0.634*	0.808	0.546	0.002	0.050	7.807*	0.634±0.050*
Flakiness Ratio, R_f	KAT-B1	0.820*	1.030	0.617	0.006	0.076	9.218*	0.820±0.076*
	KAT-B9	0.825*	1.491	0.475	0.017	0.131	15.847*	0.825±0.131*
	SCR-15	0.706*	0.919	0.555	0.005	0.070	9.953*	0.706±0.070*
Sphericity, φ	KAT-B1	0.711*	0.838	0.576	0.002	0.043	6.116*	0.711±0.043*
	KAT-B9	0.688*	0.808	0.566	0.003	0.050	7.272*	0.688±0.050*
	SCR-15	0.656*	0.806	0.581	0.002	0.039	5.993*	0.656±0.039*
Roundness	KAT-B1	0.675*	0.776	0.541	0.002	0.049	7.250*	0.675±0.049*
	KAT-B9	0.659*	0.836	0.462	0.005	0.074	11.155*	0.659±0.074*
	SCR-15	0.596*	0.753	0.505	0.002	0.047	7.811*	0.596±0.047*

******Significant at P≤ 0.05,* ^{ns}*non-significant, CV = Coefficient of Variation, VARA = variance, STDEV = Standard deviation*

Table 2 presents an overview of the outcomes the statistical description of gravimetric characteristics that were measured and determined. The average moisture content values were found to be 12.867±0.321% on a dry basis, mass of one thousand seed (378.167 ± 31.608 kg), bulk density (793.40 ± 34.11 kgm^{-3}), true density (1234.71 ± 34.03 kgm^{-3}), and porosity (35.714 ± 3.17%) for selected varieties. Similar trends were reported for common beans by (*Amin et al., 2004*), faba beans by (*Altuntas and Yildiz, 2007*), barbunia beans by (*Cetin, 2007*), white speckled red kidney beans by (*Isık and Unal, 2007*), and for red bean grain and common bean seed by (*Saparita et al., 2019*). Nevertheless, compared to the studies of *Altuntas and Yildiz (2007)* and *Cetin (2007*), these increases in the bulk and dimensions of the size variants as influenced by moisture content were smaller.

Table 2

Statistical description of gravimetric properties of selected *Phaseolus vulgaris*

Variety	Mc db%	TSM, kg	Bulk Density, kgm^{-3}	True Density, kgm^{-3}	Density Ratio	Porosity,%
KAT-B1	13.10	342.00	827.000	1217.0800	0.679495	32.0505
KAT-B9	12.50	392.00	794.400	1273.9375	0.623578	37.6422
SCR-15	13.00	400.50	758.800	1213.1000	0.625505	37.4495
Mean	12.867^{ns}	378.167^{ns}	793.400^{ns}	1234.706^{ns}	0.643*	35.714*
Max	13.100	400.500	827.000	1273.938	0.679	37.642
Min	12.500	342.000	758.800	1213.100	0.624	32.050
Range	0.600	58.500	68.200	60.837	0.056	5.592
Variance	0.103	999.083	1163.560	1158.303	0.001	10.076
STDEV	0.321	31.608	34.111	34.034	0.032	3.174
CV%	2.498	8.358	4.299	2.756	4.938	8.888
Mean±STDEV	12.867^{ns} ±0.321	378.167^{ns} ±31.608	793.40^{ns} ±34.11	1234.71^{ns} ±34.03	0.643*±0.032	35.714*±3.17

**Significant at P≤ 0.05, ns non-significant, CV = Coefficient of Variation, Mc = Moisture content, TSM =Thousand seed mass, STDEV = Standard deviation*

Table 3 shows static coefficient of friction for different sliding surface materials with a single seed/minimum value and the remaining seeds/maximum value sliding on a selected surface. The static coefficient of friction on the iron sheet surface varied from 0.276 to 0.386 with average mean value (amv) of 0.344 ±0.114, on the stainless steel from 0.294 to 0.435 with amv of 0.355 ±0.106, on the galvanized iron from 0.317 to 0.434 with amv of 0.372 ±0.110, on the MDF sheet from 0.321 to 0.451 with amv of 0.373 ±0.139, on the aluminum from 0.319 to 0.480 with amv of 0.393 ±0.26, on the perforated sheet from 0.462 to 1.048 with amv of 0.639 ±0.279, on the painted sheet from 0.310 to 0.470 with amv of 0.412 ±0.125, on the glass from 0.320 to 0.440 with amv of 0.388 ±0.105, on the plastic from 0.333 to 0.447 with amv of 0.383 ±0.095 and on the rubber from 0.374 to 0.575 were amv of 0.495 ±0.172, respectively. The moisture content and the coefficient of friction generally have a proportional relationship on all surfaces. Perforated sheet surfaces showed the highest static coefficients of friction, followed by rubber, plastic, plywood, glass, aluminum, galvanized iron, painted sheet, stainless steel and iron sheet surfaces. Similar patterns have been found for black-eyed peas (*Desphande et al., 1993*), cumin seed (*Singh & Heldman, 2009*), red kidney beans, soybeans, unshelled peanuts, black-eyed peas (*Mohsenin, 1986*), and lentil seeds (*Saparita et al., 2019*).

The table 3 shows the mean, variance, standard deviation, and coefficient of variation (CV %) for the angle of inclination (ϕ) and static coefficient of friction (μs) for different sliding surface materials and common bean genotypes. All the values shown are statistically significant at the p≤0.05 level. Compared to perforated sheet, rubber, plastic, plywood, glass, aluminum, galvanized iron, painted sheet, stainless steel and iron sheet surfaces, the angle of repose for common beans increased proportionally as the moisture content increased. The average mean value (amv) of the inclination in the following surfaces: iron sheet surface: 18.113±5.813, stainless steel: 19.057 ±5.58, galvanized iron: 19.00 ±7.54, MDF sheet: 19.557 ±6.913, aluminum: 19.667 ±6.757, perforated sheet: 28.667 ±9.270, painted sheet: 21.390±6.367, glass: 20.113 ±4.87, plastic: 18.777±4.713, and rubber: 24.163 ±8.567, respectively. Based on the results, the average suggested angle of repose for common bean seeds should be within 27.1º to 32.4º. According to *Mohsenin (1986),* the angle of repose for common bean seed was determined to be between 27.1º and 35.4º, which are still below the maximum angle of repose of 45^0 for the majority of agricultural commodities.

Table 3

Statistical description frictional properties of *Phaseolus vulgaris* on various types of sliding surface materials

Surface	Common bean varieties	Angle of inclination, ϕ					Static coefficient of friction, µs				
		Mean	VARA	STDEV	Mean±STDEV	CV%	Mean	VARA	STDEV	Mean±STDEV	CV%
Iron sheet	KAT-B1	17.50*	16.06	4.01	17.50±4.01*	22.90*	0.316*	0.01	0.08	0.316±0.08	24.34
	KAT-B9	18.67*	56.89	7.54	18.89±7.54*	40.41*	0.341*	0.02	0.15	0.341±0.15	43.16*
	SCR-15	18.17*	34.72	5.89	18.17±5.89*	32.44*	0.330*	0.01	0.11	0.330±0.11	34.59*
Stain-less steel	KAT-B1	20.33*	37.56	6.13	20.33±6.13*	30.14*	0.373*	0.01	0.12	0.373±0.12	32.70
	KAT-B9	17.67*	32.00	5.66	17.67±5.66*	32.02*	0.320*	0.01	0.11	0.320±0.11	34.03*
	SCR-15	19.17*	24.50	4.95	19.17±4.95*	25.82*	0.349*	0.01	0.10	0.349±0.10	27.79
Galvanized Iron	KAT-B1	17.50*	34.72	5.89	17.50±5.89*	33.67*	0.317*	0.01	0.11	0.317±0.11	35.74*
	KAT-B9	18.33*	26.89	5.19	18.33±5.19*	28.28*	0.333*	0.01	0.10	0.333±0.10	30.23
	SCR-15	19.00*	56.89	7.54	19.00±7.54*	39.70*	0.351*	0.02	0.15	0.351±0.15	43.51*
Ply-wood	KAT-B1	20.00*	56.89	7.54	20.00±7.54*	37.71*	0.368*	0.02	0.15	0.368±0.15	40.72*
	KAT-B9	19.17*	46.72	6.84	19.17±6.84*	35.66*	0.350*	0.02	0.13	0.350±0.13	38.29*
	SCR-15	19.50*	40.50	6.36	19.50±6.36*	32.64*	0.357*	0.02	0.13	0.357±0.13	35.15
Alumi-num	KAT-B1	19.17*	53.39	7.31	19.17±7.31*	38.12*	0.351*	0.02	0.14	0.351±4.01	40.90*
	KAT-B9	17.83*	40.50	6.36	17.83±6.36*	35.69*	0.324*	0.02	0.12	0.324±0.12	37.94*
	SCR-15	22.00*	43.56	6.60	22.00±6.60*	30.00*	0.407*	0.02	0.13	0.407±0.13	33.02*
Perfo-rated sheet	KAT-B1	31.00*	107.5	10.37	31.00±10.37*	33.45*	0.614*	0.06	0.25	0.614±0.25	40.55
	KAT-B9	28.17*	76.06	8.72	28.17±8.72*	30.96*	0.544*	0.04	0.20	0.544±0.20	36.29
	SCR-15	26.83*	76.06	8.72	26.83±8.72*	32.50*	0.513*	0.04	0.19	0.513±0.19	37.50*
Painted sheet	KAT-B1	23.67*	37.56	6.13	23.67±6.13*	25.89*	0.441*	0.02	0.13	0.441±0.13	28.98
	KAT-B9	20.17*	53.39	7.31	20.17±7.31*	36.23*	0.371*	0.02	0.15	0.371±0.15	39.19*
	SCR-15	20.33*	32.00	5.66	20.33±5.66*	27.82*	0.373*	0.01	0.11	0.373±0.11	30.20
Glass	KAT-B1	20.67*	18.00	4.24	20.67±4.24*	20.53	0.378*	0.01	0.08	0.378±0.08	22.38
	KAT-B9	19.67*	22.22	4.71	19.67±4.71*	23.97*	0.359*	0.01	0.09	0.359±0.09	25.90
	SCR-15	20.00*	32.00	5.66	20.00±5.66*	28.28*	0.366*	0.01	0.11	0.366±0.11	30.62
Plastic/ Maica	KAT-B1	19.67*	18.00	4.24	19.67±4.24*	21.57*	0.359*	0.01	0.08	0.359±0.08	23.32
	KAT-B9	18.33*	22.22	4.71	18.33±4.71*	25.71*	0.333*	0.01	0.09	0.333±0.09	27.49
	SCR-15	18.33*	26.89	5.19	18.33±5.19*	28.28*	0.333*	0.01	0.10	0.333±0.10	30.23
Rubber	KAT-B1	24.83*	46.72	6.84	24.83±6.84*	27.52*	0.467*	0.02	0.15	0.467±0.15	31.15
	KAT-B9	23.33*	98.00	9.90	23.33±9.90*	42.43*	0.439*	0.04	0.21	0.439±0.21	47.04*
	SCR-15	24.33*	80.22	8.96	24.33±8.96*	36.81*	0.459*	0.04	0.19	0.459±0.19	41.30

*****Significant at $P \leq 0.05$, ns non-significant, CV = Coefficient of Variation, VARA = variance, STDEV = Standard deviation*

CONCLUSIONS

In this study, the engineering properties of *Phaseolus vulgaris* seeds are determined that may provide opportunities to design construct and develop harvesting, handling, and processing machinery for *Phaseolus vulgaris* seeds by considering their physical and frictional characteristics. Experimental analysis was used to accomplish the study's objective, which was to investigate the implications of variation on the physical characteristics and frictional parameters of common beans (Phaseolus vulgaris L.) concerning the design of the threshing machine. The mean average values of physical parameters were determined by analyzing the experimental data: length (11.282 ± 0.995 mm), width (7.24 ± 0.673 mm), thickness (5.67 ± 0.794 mm), elongation of width (1.566 ± 0.136 mm), elongation of thickness (2.037 ± 0.282 mm), elongation of vertical (1.301 ± 0.152 mm), arithmetic mean diameter (8.064 ± 0.688 mm), geometrical mean diameter (7.715 ± 0.698 mm), square mean diameter (13.646 ± 1.195 mm), equivalent mean diameter (9.808 ± 0.859 mm), roundness (0.644 ± 0.056), sphericity (0.685 ± 0.044), flakiness ratio (0.784 ± 0.092), aspect ratio (0.643 ± 0.053), cross-sectional area (154.477 ± 26.002 mm^2), projected area (64.508 ± 10.377 mm^2), transverse surface area (32.546 ± 6.683mm^2), and the seed volume (241.744 ± 0.207 mm^3), respectively.

The static coefficient of friction varied between 0.276 and 0.386 on the surface of iron sheets, 0.294 to 0.435 on stainless steel, 0.317 to 0.434 on galvanized iron, 0.321 to 0.451 on medium density fiberboard, 0.319 to 0.480 on aluminum, 0.310 to 0.470 on painted sheets, 0.320 to 0.440 on glass, 0.333 to 0.447 on plastic, and 0.374 to 0.575 on rubber. Perforated sheet surfaces showed the highest static coefficients of friction, followed by rubber, plastic, plywood, glass, aluminum, galvanized iron, painted sheet, stainless steel, and iron sheet surfaces. These results data are frequently needed to establish a convenient reference required to develop equipment for handling, cleaning, storing, transporting, drying, and other processes, as well as for predicting loads in agricultural storage structures and resolving flow issues in agro-processing. More research ought to be done to investigate the enhanced Phaseolus vulgaris cultivars' moisture-dependent engineering characteristics.

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